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CLARC: A Cognitive Robot for Helping Geriatric Doctors in Real Scenarios

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Abstract. Comprehensive Geriatric Assessment (CGA) is an integrated clinical process to evaluate the frailty of elderly persons in order to create therapy plans that improve their quality of life. For robotizing these tests, we are designing and developing CLARC, a mobile robot able to help the physician to capture and manage data during the CGA procedures, mainly by autonomously conducting a set of predefined evaluation tests. Built around a shared internal representation of the outer world, the architecture is composed of software modules able to plan and generate a stream of actions, to execute actions emanated from the representation or to update this by including/removing items at different abstraction levels. Percepts, actions and intentions coming from all software modules are grounded within this unique representation. This allows the robot to react to unexpected events and to modify the course of action according to the dynamics of a scenario built around the interaction with the patient. The paper describes the architecture of the system as well as the preliminary user studies and evaluation to gather new user requirements.

Keywords: Assistive robotics · Human-robot interaction

1 Introduction

Comprehensive Geriatric Assessment (CGA) is a clinical procedure for the evaluation of frailty of older people and adequate treatment prescription. CGA is an interdisciplinary effort, requiring the coordination of several clinical professionals with the aim of increasing both the quality and quantity of life of elderly people. Improving the diagnosis, creating right, customized and proportional therapeutic plans, increasing functional autonomy, and also reducing complications during hospitalizations and mortality are some of its benefits. Considering the aging of the world population, CGA importance, and costs related to it, are by no doubt going to be increased.

CGA is usually carried out every 6 months and involves both patients and relatives. It comprises three different types of activities: clinical interview, multidimensional assessment and customized care plan. First, a clinical interview allows patient and relatives to discuss the elder health problems with the physician. Next, multidimensional clinical tests are performed to evaluate the overall patient status. Finally, taking into account the evidences gathered during the two previous phases and the patient's evolution since the last CGA session, physicians create a personalized care plan. A typical CGA session takes about 3 h of clinician's time. Some of the activities require the clinical staff to be present, but other ones, particularly the multidimensional assessment, are standard tasks suitable for automation and/or parallelization. Discharging part of the CGA on a robot allows clinicians to focus on activities with more added value, like deciding, together with the patient and relatives, the appropriate care plan. In this paper we introduce a prototype of CLARC[1], an autonomous robotic solution to support CGA. From a conceptual perspective, CLARC can be divided into two differentiated subsystems. The *Cognitive subsystem* is mainly focused on the robot autonomy and its interaction with the patient. The *CGAMed* subsystem focuses on the interface with the clinicians and the Clinical Data Management System (CDMS). In a typical CGA session, the clinician will use the CGAMed interface to setup the tests to be performed. Then, the robot will conduct the tests autonomously and will store the results in the CGAMed database. Finally, the clinician will use again the CGAMed interface to review the session outcomes in order to create a new care plan. The main contributions of the paper are the description of the cognitive architecture that controls CLARC, the preliminary user studies and the lessons learnt from them.

2 CGA Tests

CLARC is currently able to perform three tests: one functional test (Barthel [1]), one cognitive test (MMSE [2]) and one motion analysis test (Get Up & Go [3]). The robot is designed to be able to include more CGA tests easily, or even allow the clinician to design new ones. Tests include closed-answer questions ("select option 1, 2 or 3"), open-answer questions ("What day is it today?") and monitoring of simple ("close your eyes") or complex ("get up from the chair and walk three meters") patient movements. CLARC is intended to work with real patients in real-life hospital environments, thus it needs to be much more than a simple survey tool. The hypothesis driving the design of the first prototype, confirmed by the results of the user studies, is that CLARC's Automated Planning abilities allow to plan the interaction with the user and to adapt to exogenous events, like the patient asking for help or leaving the room. Before driving the

[1] http://echord.eu/essential_grid/clark/.

tests, CLARC robot needs to introduce itself as an accessible and helpful *assistant* (or, at least, tool). Elderly people undergoing CGA procedures are usually not familiar at all with robotic technologies. It is crucial for CLARC to make them feel comfortable and reassured, and offer them natural and intuitive ways to interact. During the tests CLARC collects, saves and displays the responses. Using the CGAMed interface, the physician can monitor the tests on-line or to access to their results once the test finished.

- **The Barthel test.** The Barthel test is a heteroadministered test composed of ten questions about daily life activities, following a Likert scale structure, where each situation is described. It usually lasts about 10–15 min. The test can be filled by the patient, or a relative/caregiver, and it can be related to present or past conditions. The robot is currently able to ask questions using natural interaction channels (i.e. voice output and text on screen). For each question, two, three or four possible answers are offered. The person can answer questions either speaking or touching the option on the screen.
- **The MMSE test.** The Mini-Mental State Examination (MMSE) is a screening test composed of thirty questions, extensively employed to measure cognitive impairment. It usually lasts around 10–15 min and must be performed by the patient. MMSE includes questions that require the patient to move, or perform certain gestures and actions like drawing, writing sentences or recognizing images. These requirements make this test much more challenging to automate than the Barthel test. CLARC collects answers using voice recognition, the touch screen, and a tablet device that is offered to the patient to answer certain questions (e.g. those related to drawing).
- **The Get Up & Go test.** In this test, the patient is asked to stand up from a chair, walk a short distance (around three meters) following a straight line, turn back, return to the chair and sit down. The goal is to measure balance, detecting deviations from a confident, normal performance. CLARC has to give instructions to the patient, position itself in a proper location to observe the complete motion, and provide a signal to start the test. For a successful automation of the test, the robot needs to perceive the gait and to analyze balance and timing issues.

3 Cognitive Architecture

The cognitive architecture of the CLARC system handles the interaction with the patient and the robot's autonomy. A schematic view is shown in Fig. 1. It is a specific instantiation of the CORTEX architecture for robotics [4]. CORTEX proposes a distributed architecture, where action execution, simulation and perception are intimately tied together, sharing a common representation, the Inner World. In the CGA scenario, this internal representation of the robot, the patient and any other external significant event, is the central part of the architecture for action control. All task-solving elements of CORTEX (the Panel, Tablet, Speech, etc. see Fig. 1) use this central representation to share data at different abstraction levels, to get information about the user's state and to plan next actions.

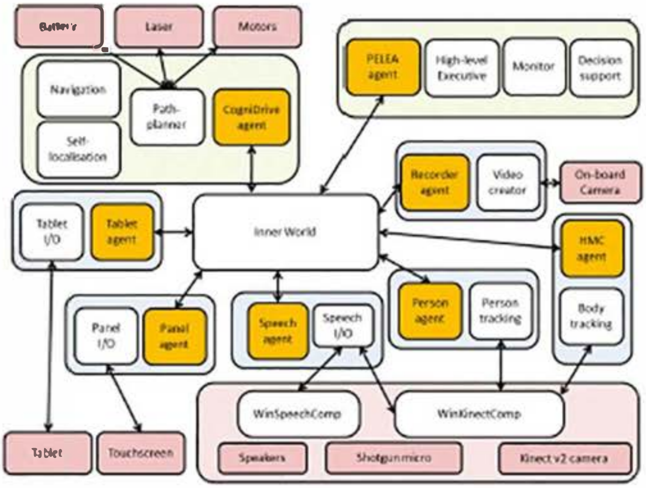


Fig. 1. CLARC cognitive architecture.

Software modules are organized on networks of components (*compoNets*), which are linked to the Inner World through specific modules, the so-called *agents*. The robot's course of action emerges from the activity of all these *compoNets*. There are currently seven *compoNets* within the software architecture of CLARC. They are represented in Fig. 1 by blue or green-filled rectangles. Blue-filled ones are reactive *compoNets*. They are able to introduce/remove perceptual entities on the Inner Word (e.g. a person, the robot's joints, a recognized sentence...) and to act on the environment through a specific interface. Green-filled *compoNets* are deliberative and include a planner able to generate a course of actions for solving a specific problem. Red boxes represent low-level sensors and actuators.

The architecture is designed to be embodied within the CLARC robot (see Fig. 2a). Its base is a MetraLabs SCITOS G3 platform. The outer shell is currently being redesigned to customize it for the specific CGA needs, following two participatory co-design sessions with users and MetraLabs' engineers'/designers. The robot's locomotion is based on a differential drive system consisting of two powered wheels and a caster wheel for stability. This enables the robot to rotate on the spot and drive at a speed of up to 1 m/s, if necessary. The platform is fitted with a LIDAR sensor for localization, navigation and obstacle avoidance. It is extended with an extensive human-machine-interface, consisting of a Microsoft Kinect V2 sensor, a shotgun microphone, a touch screen, speakers, a web cam for recording the sessions, and a tablet that the patient can use to interact with the robot if needed.

3.1 The Inner World

Within CORTEX, the Inner World is encoded using the Deep State Representation (DSR) [4]. The DSR is a multi-labeled directed graph which holds symbolic

(a) (b)

Fig. 2. (a) Prototype of the CLARC robot; (b) CLARC robot driving the Barthel test.

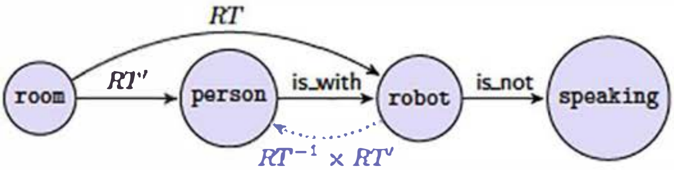


Fig. 3. Unified representation as a multi-labeled directed graph.

and geometric information within the same structure. The nodes of the DSR store concepts that can be symbolic, geometric or a mixture of both. Metric concepts describe numeric quantities of objects in the world that can be structured like a three-dimensional mesh, scalars like the mass of a link, or lists like revision dates. Edges represent relationships among symbols. Figure 3 shows a simple example. The person and robot nodes are geometrical entities, both linked to the room by rigid transformations RT and RT'. It is possible to compute the geometrical relationship between both nodes ($RT^{-1} \times RT'$). On the other hand, using logic predicates within the representation, the person can be located (is_with) close to the robot. Furthermore, an agent can annotate that currently the robot is_not speaking.

Each *compoNet* includes an *Agent* that is in charge of reading and updating the Inner World, and guarantees all *compoNets* are synchronized. Sharing data in the Inner World allows both planned and reactive behaviours emerge from stigmergic relations. An example of these relations: Fig. 4 shows the sequence of updates that occurs when the robot speaks. In this example, when the planner goes to the next step in the test (change in the is_in edge between Test and Test part nodes), the speech agent realizes that CLARC needs to say a sentence, and changes the is_not link between Robot and Speaking accordingly. The sentence

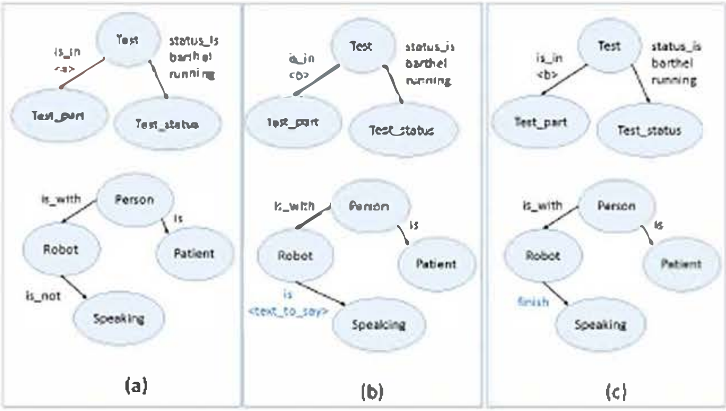


Fig. 4. Example of Speaking to the patient: (a) Inner World before the action; (b) Inner World while speaking; and (c) Inner World after the action.

to be said appears as an attribute in this link. Other agents can use these data, such as the recorder in charge of creating subtitles for the videos shown to the clinician. Once the robot finishes speaking, the Speech *compoNet* changes again this edge from `is` to `finished`. The planner uses the appearance of this edge as an acknowledgement of the sentence having been successfully spoken.

3.2 The Deliberative Module

This module is in charge of providing task-autonomy to the robot by means of Automated Planning. When the clinician selects the test(s) to be performed, the current state of the robot and of the environment are recovered by the PELEA [5] agent from the Inner World and an issue in the Planning Domain Definition Language (PDDL) [6] is created. This issue, together with a PDDL domain, which contains the description of the actions that the robot can perform, the conditions under which they can be executed and the changes they produce in the world, are sent to the *Decision Support* (DS) module, which wraps an automated planner (currently the CBP planner [7]). The DS returns a plan, containing the sequence of actions that the robot must perform to fulfill its goals, i.e. to perform the tests. Then the *High Level Executive* (HLE) module takes the first action of the plan and decomposes it into low-level actions understandable by the reactive *compoNets* of the robot. These actions are then inserted into the Inner World to be executed. As a result of the execution and of the patient's feedback, the Inner World is updated. Changes in the Inner World are sent to *Monitoring* that checks whether the plan is executing as expected. It is in charge of invoking again the DS module if any deviation in the execution of the plan arises. It could detect, for example, that the user has not answered a question or is not facing the robot; in both cases, DS finds alternate plans to solve the problem found by calling again the automated planner.

3.3 Reactive compoNets

These *compoNets* collect data through sensors, update the Inner World, and produce responses (actions) in the robot. *Speech* is in charge of making CLARC speak, listen and understand. The voice of CLARC is generated from text using the Text-To-Speech (TTS) software provided by the Microsoft Speech Platform SDK. This software is also used for voice recognition, with the help of specific grammars that are loaded for each question, in order to maximize recognition rates. The SpeechAgent component updates the Inner World adding attributes to edges and nodes to indicate whether the person and the robot are speaking or not. *Panel* is in charge of controlling CLARC's touch screen, used to display the patient-robot interface, and to collect patients' answers. *Tablet* allows a person to write text and draw figures using an Android Tablet, as required in some questions of the MMSE test. It also includes image processing algorithms required to evaluate the drawings. *Person* is in charge of tracking the person and selecting the relevant user, depending on the current state of the robot. It processes particular gestures (required for some questions in the MMSE test), monitors the behaviour and position of the person, and updates the Inner World with that information. It uses the Microsoft Kinect SDK. *HMC* is in charge of analyzing human gait. It is able to track the body motion of the patient, store it and analyze it when necessary. It includes parameter-based gait analysis algorithms that process the motion, firstly dividing it into discrete actions, and then evaluating each action separately. *CogniDrive* handles the robot movements. It integrates the CogniDrive software by MetraLabs allowing the robot to navigate and self-localize in indoor, office-like environments.

4 User-Centred Evaluation

The previous sections described the technological system architecture. However, beyond technical performance, to ensure that the robot is an efficient assistant that can autonomously take charge of the standard tests, it is required that both the doctor and the patient can *trust* it. This is why this interdisciplinary research adopts a user-centred design approach [12] to look into the technology usage question. Based on preliminary user studies and evaluation of the working prototype, a four-days participatory workshop was held at one of the partners' university Living Lab. This Living Lab (Fig. 2b) offers an operational apartment environment attached to a high-technology-equipped control room, and a creativity lab. This section succinctly presents the design of this evaluation: participants, objectives, as well as the new user requirements gathered and how these insights informed the recent redesign of a second version of CLARC robot, that is more user-friendly, helpful and useful.

4.1 Participants, Methods and Objectives

The workshop brought together researchers and different actors concerned by CGA: seniors (informal caregivers) and elderly people, health professionals and health-care center managers. A qualitative research approach complementarily combined a collection of common user-study techniques widely used in Human-Computer Interaction research discipline [11]:

- *user tests* with predefined tasks followed by debriefing interviews. The objective was to gather feedback about the robot performing tests, including the main interface (see section below). Then, the tests were immediately followed by 20-minutes debriefing interviews to collect users' feedback and suggestions. Sixteen users performed the user tests and debriefing interviews (Barthel: 13 users; Get up and Go: 11; MMSE: 3). Two were health professionals, and the others were seniors/elders, among which 10 women and 4 men, aged 60–70 years (5), 70–80 years (4), 80–90 years (3), +90 years (2).

- *semi-directive interviews* were done with six health professionals (4 women, 2 men; 2 geriaticians, a geriatric nurse, a coordinating nurse in a retirement home, a nurse trainer, a physiotherapist). They were asked about their current practice in doing CGA: the process at their hospital, the collaboration/delegation with other health professionals, data collection and sharing (paper and/or digital patient records), what information is needed to make a diagnosis, the type of interaction with the patients (is/should there be more time for the relational aspects), and finally their opinion about the added value of the robot in their practice.

- *focus groups* with elderly people and health professionals, to gather information about what they would expect in CGA tests held by robots. Twenty participants attended the focus groups (2 groups of 10), composed of 14 seniors and 6 health professionals. The seniors were 12 women and 2 men, aged 60–70 years (5), 70–80 years (5), 80–90 years (2). The health professionals were 4 women and 2 men, all related to geriatrics, functional evaluation and medical-technical services. The reflection, based on brainstorming and post-it sessions collectively examined: What does geriatric evaluation evoke to you? What is an ideal medical consultation? How can the robot inspire trust to both patients and clinicians - in terms of appearance, mobility, speech? What type of form would be the most appropriate - on a continuum from ballish to humanoid?

The main issues that were examined in this preliminary evaluation were the envisaged added value of the robot, the human-robot interaction, the usefulness of the robot for CGA tests, and preliminary reflections about the interface of the first prototype of the robot. The user requirements collected led to valuable design decisions to improve both interface and interaction.

4.2 Results Analysis

Sixteen users performed different user tests with the Robot - 13 users performed the Barthel test (11 seniors and 2 health professionals); 11 users performed the Get up and Go (the same as for the Barthel, except two ladies aged 90+), and just three senior users were asked to perform the MMSE test (different users as for the previous test, which ran in English, not in French). The Get up and Go tests could not be achieved autonomously for any user, because of, either bugs or difficult interaction, due mainly to unclear instructions of actions to be achieved by users. The average duration time for each test is Barthel: 13'48 min; Get up and Go: 2'27 min; MMSE: 26'37 min.

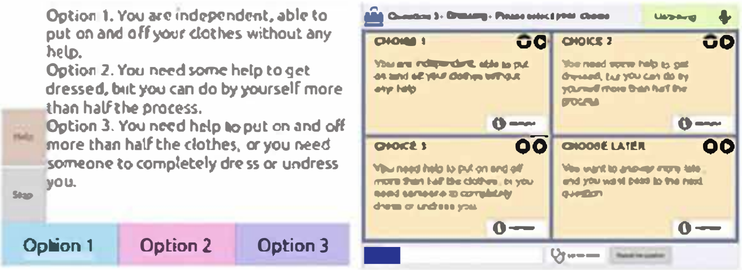
The Barthel tests were successfully completed by all the users, despite some difficulties for older ones: a 93 year old lady completed the test with her daughter's help, two other ladies (aged 87 and 93) visibly had difficulties understanding the interaction with the robot. Despite older participants' difficulties - which they did not admit during the interviews - the users were all generally satisfied.

During the debriefing interviews, users answers to different questions operationalized with five-point Likert scales (from 1 = strongly disagree to 5 = do fully agree). Next, the main results of these interviews are summarized. Concerning the overall interaction with the robot and whether users felt any apprehension or discomfort concerning the robot's physical aspect or when interacting with it, for all the users, the feedback is mostly positive or neutral, except for one user who declared not feeling at ease in the robot's presence (Mean -M-:3,5; Standard Deviation -SD-:0,85; Mode -m-: 3; number of answers -n-:10). All the users, except one, declared having no difficulty hearing and understanding the TTS synthesized voice and reading the text on the screen (M:4.5;SD:0,97;m:5;n:10).

All users, except one, declared having no difficulties hearing/understanding the Text-to-Speech, even though the test is perceived as being long. However, their impression of "speaking naturally" with the robot is, for all of them, mitigated - neutral between a positive and negative perception. Concerning the interaction, most users considered it as being engaging (M:3,7;SD:0,82;m:4;n:10). In terms of clarity of the robot's explanations of actions to be done by users, most users consider them positively (M:3,8;SD:0,78;m:4;n:10).

Finally, the users were asked about their experience in other CGA tests, if they feel more comfortable talking of difficult subjects (such as incontinence, sexual problems, etc.) with a robot or with a health professional. Seven senior users answered to this question, noting that four of the answers declare preferring the robot, just two persons preferred the health professional and for one person was completely indifferent.

On the other hand, during the debriefing interviews, users could make observations about specific problems found during the interaction. They could express their opinion very subjectively, coherent with our qualitative approach, based on in situ and video recorded observations of actions during the tests. The explanations for the Get up and Go presented by the robot were difficult to understand for all the users, because it was too long, asking the user to perform different tasks. This will be revised: the verbal explanation will be accompanied by a video demo. However, despite these negative results in terms of effectiveness and efficiency, users' feedback concerning their satisfaction of doing such a test with the robot was rather positive (as we can observe in the previous questions), since they perceived the potential added value with clearer instructions. Related to the MMSE test, some users had some problems linked to the Automatic Speech Recognition software, due to the fact that their oral answers were not always correctly taken into account. Moreover, some of the robot's instructions were



(a) (b)

Fig. 5. (a) Old and (b) New interface of the Barthel test.

considered too direct and quite rude. All these interaction problems are now been revised by the robot's designers.

The main insight emerging from interviews with the health professionals is the unanimously perceived added value of the robot. Mainly allowing time saving, the robot would make possible, either more relational work or receiving a greater number of patients (solving part of the waiting time for having a CGA). Concerning the way the CGA process itself is done across countries and institutions, many differences appear. We deduce the necessary adaptability of the robot to the organizational context specific of each institution.

The focus groups' main insight is that the patient needs to have the feeling of existing as a person (not as a patient record number): being known and recognized, either by the clinician according more attention, or, concerning the robot, having the feeling that it is not just a machine. *Time*, *trust*, and *empathy* are the three main keywords of an ideal consultation. Interestingly, they apply both to clinicians and the robot. Roundish, but without any human characteristics is the general desired shape for the robot.

5 Discussion

The insights - from user tests, interviews and focus groups - informed the improving the interface and interaction, as shown in Fig. 5, with new functions and elements added, such as a progress bar and a title containing the number and theme of the question to facilitate location in the test, or a "Choose later" option to ensure exact answers. Another example of improvement is related to the dialogue system. Because of the characteristics of voice technology, the input and output need to alternate, with longer pauses in between turns-at-talk than in natural interaction. To avoid useless speaking while Automatic Speech Recognition (ASR) is unactivated, a "Listening" in green colour or "Not listening" in red colour indication has been included on the upper right corner (see Fig. 5). Many other suggestions have been included after this initial evaluation which has allowed to improve the interaction with the robot.

The objective for the CLARC robot is, not only to provide a user-friendly interaction and engage with the patient, but also to inspire trust - both to the patient and the doctor. From tbe interviews with the health professionals, it was possible to understand their practices and what they value. It was clear that, for them, the robot needs to be a reliable tool, and that they keep control on the robot and the test situation. The reassurance effect was also an aspect valued from users. Therefore, a *call the doctor* button was added: when it is clicked, the test is stopped and the doctor is called. This methodological framework will be replicated in another partner's hospital pilot site, and will go a step further with *in situ* field trials of the second version of the prototype, investigating the usability and accessibility of the robot.

6 Conclusions and Future Work

Most systems designed for questionnaire filling tasks do not rely on the exclusive use of natural interaction channels, and compel the user to use a keyboard or a mouse device [8]. However, recent proposals in assistive robotics focus on the use of artificial conversational systems, touch screens or a combination of botb. CLARC robot follows this approach and uses only natural interaction channels (i.e. voice and touch). To our knowledge, these multimodal interfaces have not yet been applied for automated CGA processes. Moreover, the use of Automated Planning for high level control of robots behavior has many advantages [9], like the use of a declarative language to describe the actions and current states, or the flexibility to find new plans if the current one fails. It is also a good choice to implement social interaction behaviors [10].

The use of a robotic assistant proves to effectively increase the possibilities of tbe system, as compared, for example, to a static table with a touch screen. A mobile autonomous robot is able to guide the patient, follow a clinician or navigate from one consultation room to another. It can move to the most adequate location for each phase of each test. It also offers an embodied agent that is easier to interact with. However, a robot may also raise false expectations, and it may have a too high price. These two issues, expectations and cost, are also going to be carefully balanced in the next months, according again to the feedback provided by patients, clinicians, hospital managers and caregivers, who will continue to be involved in this participatory research.

After the first design loop, CLARC robot has proven to be a technologically solid agent. It has been able to successfully drive three different CGA tests interacting with untrained users in real scenarios. Moreover, the general purpose cognitive architecture of CLARC is modular and flexible, allowing to incorporate new tests and features efficiently.

The evaluation of CLARC opens a second design and implementation loop that will last for around four months. The main goal in this new iteration is to make CLARC a more comfortable, easy to interact with and familiar platform. Thus, the screen interfaces and dialogues will be updated, a first prototype for the outer shell of CLARC will be implemented, and new options during the realization of the tests and behaviours will be also included in existing use cases to improve trust/reassurance and efficiency.

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